Probing the Thermal Fluctuations in Bulk YBCO Superconductors

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Overview

- Review of Jargon
- Experimental Objective
- YBCO Structure
- Experimental Setup/Procedure
- Polycrystalline Correction
- Experimental vs Theoretical Results
- Conclusion/Future Work

Jargon

- $\boldsymbol{T_c}$: Critical Temperature
  - Temperature at which material undergoes the phase transition into the superconducting state

- $\boldsymbol{HT_c}$: High Temperature Superconductor
  - Material whose T_c exceeds the boiling point of LN (77 K)

- Polycrystalline Structure/Polycrystallinity
  - Crystals which make up the material have random orientations in space

Experimental Objective

- Investigate thermal fluctuations in a superconductor
  - Manifests in resistivity/conductivity

Goals to achieve Objective

- Measure R(T) in sample
- Convert R into ρ_{ab}
  - Accounts for indirect current paths and possibly high contact resistance between SC grains
- Compare experimental $\Delta\sigma_{ab}(\varepsilon)$ with theoretical predictions
- Determine T_c of sample

YBCO Structure

- Yttrium barium copper oxide (YBCO)
  - $YBa_2Cu_3O_{7-\delta}$
- Bulk YBCO is a polycrystal
- SEM imaging of YBCO reveals this polycrystallinity

YBCO Structure

- Superconductivity arises within the CuO_2 layers

- Want to measure resistivity within these layers

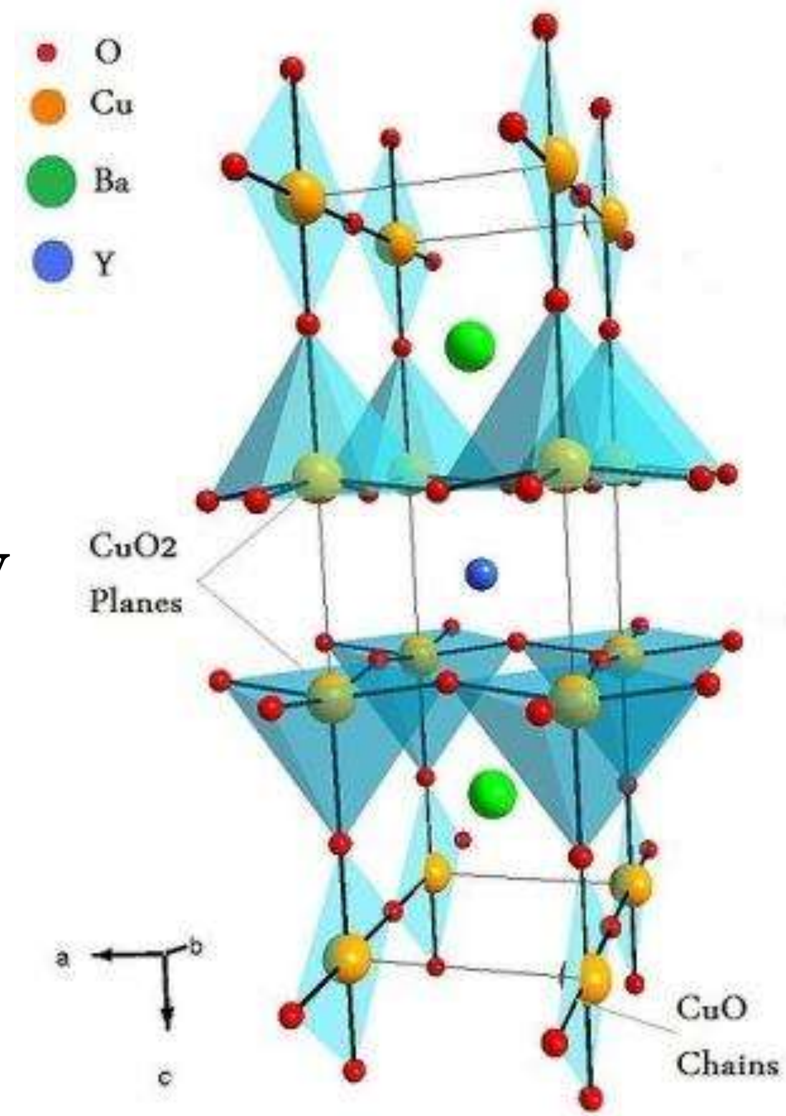


Figure 2. Depiction of the YBCO crystal structure.

SEM Imaging of YBCO

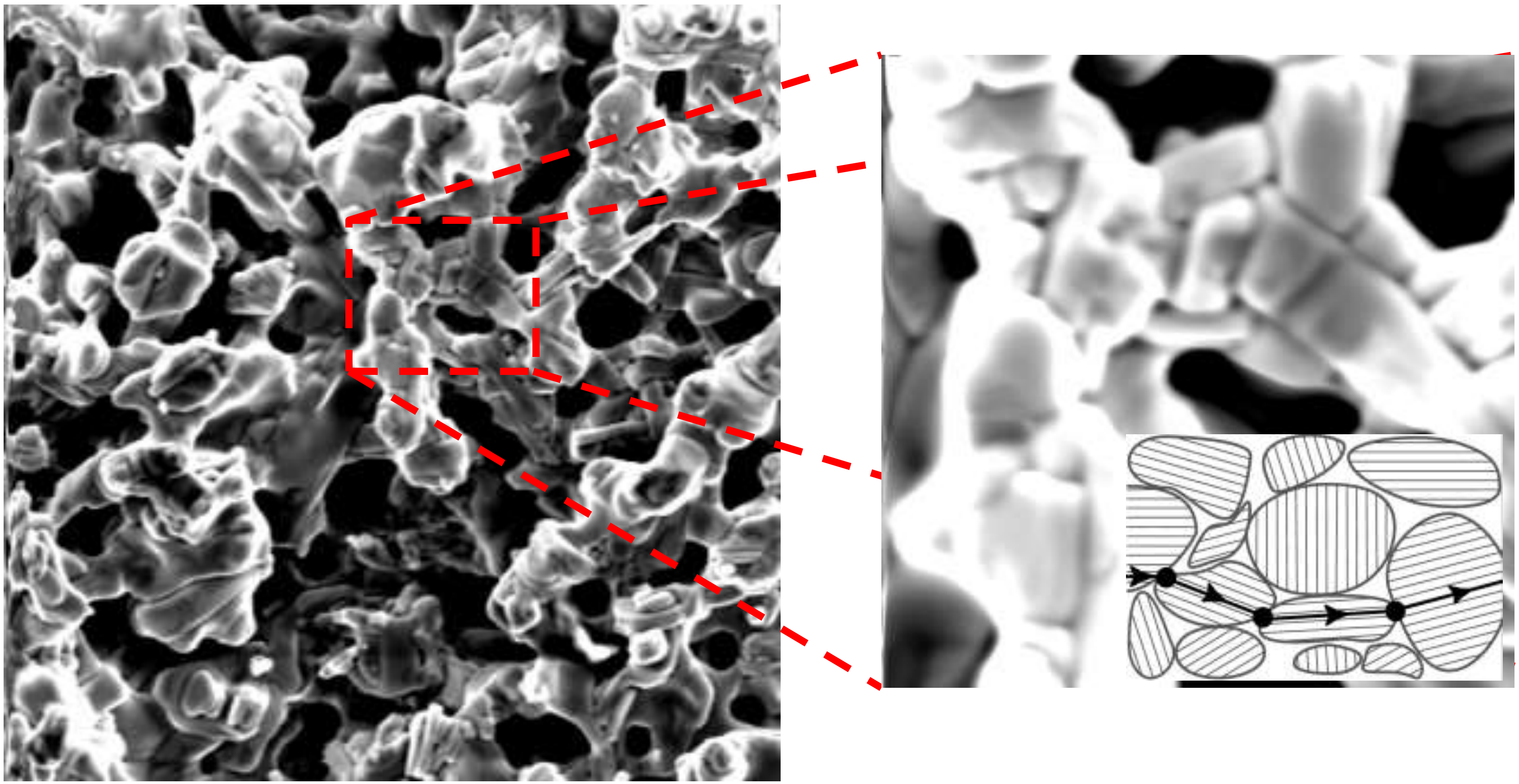


Figure 3. SEM imaging of the YBCO sample showing its polycrystalline structure.

Goal: Measure R(T) in YBCO

- Supply Current – Measure ΔV
- Utilize thermocouple to determine T

- Require ~ $10\mu v$ resolution
  - Due to bulk material + superconductor

- Common technique is the 4-pt probe method
  - Resistance measured is that **ONLY** of the sample

Review: 4-pt Probe

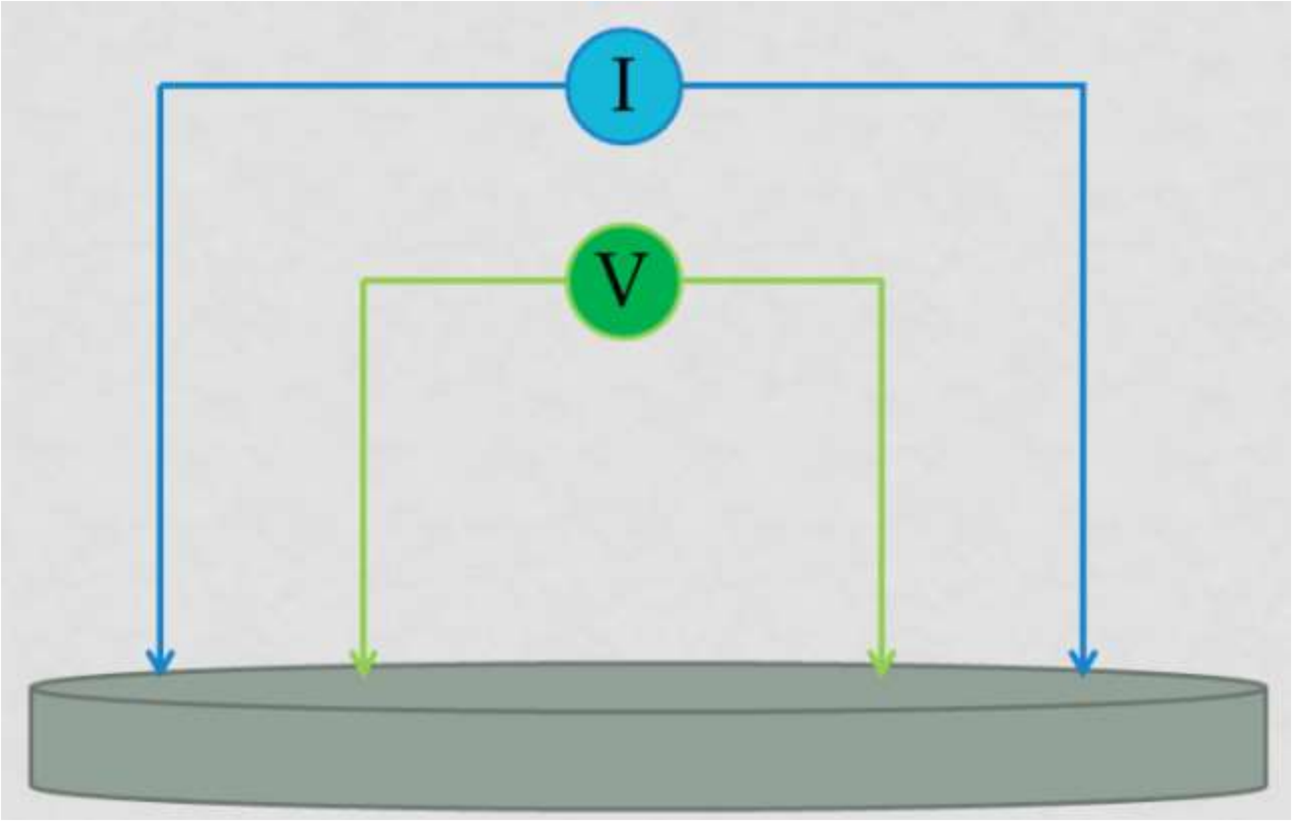


Figure 4. Depiction of the 4-pt probe used to determine resistance.

Measuring Sample Temperature

- Utilized a Type-T thermocouple (Copper-Constantan)
- $V \propto \Delta T$

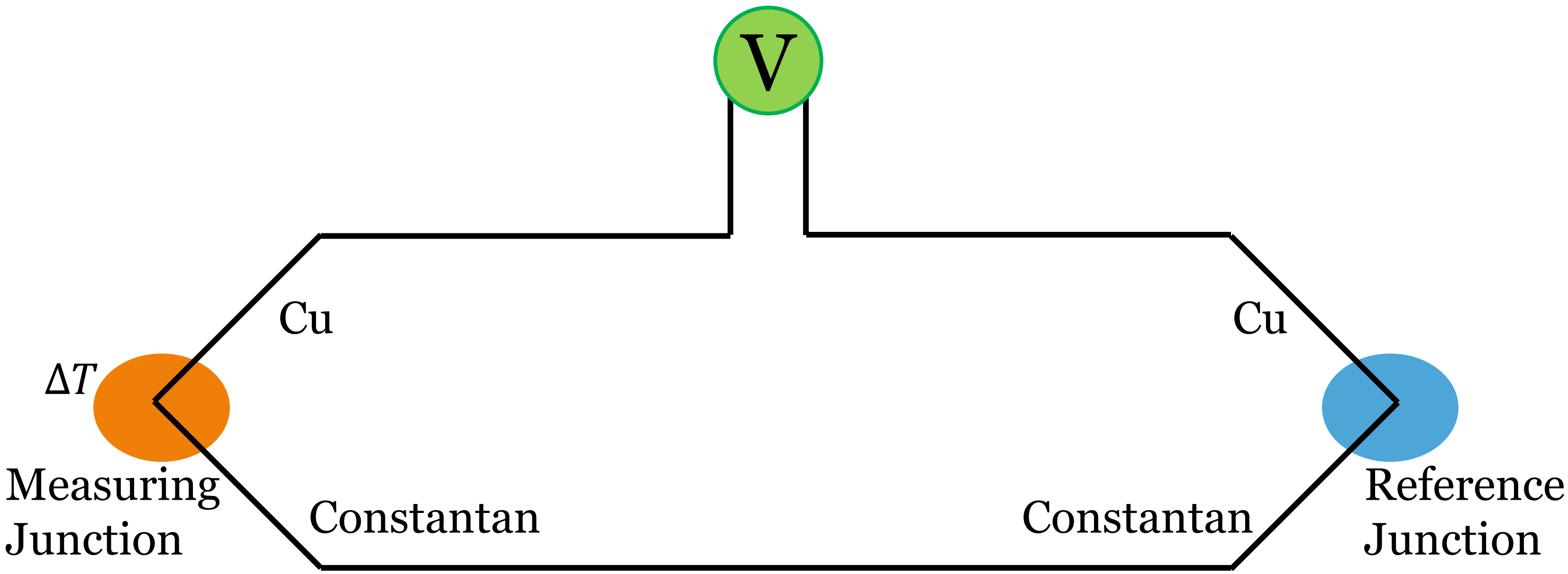


Figure 5. Depiction of a thermocouple used for measuring temperatures.

Data Acquisition using Logger Pro

- Logger Pro only has millivolt resolution
  - We require microvolt

- To circumvent, we built amplifiers to boost the measured signal
  - With enough gain, able to use Logger Pro for acquisition

Experimental Setup

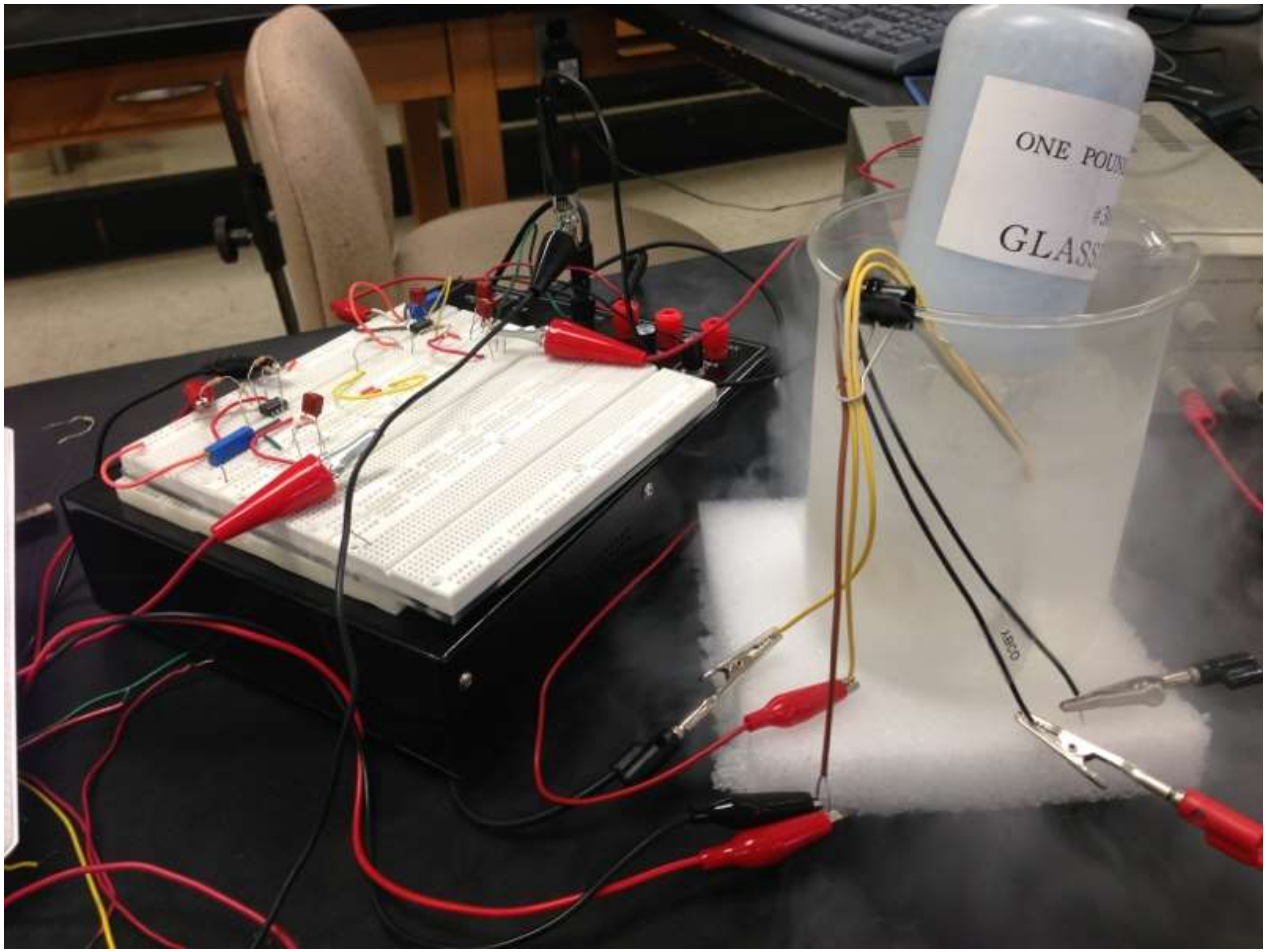


Figure 6. Photograph of the full experimental setup.

Experimental Procedure

- Fix current through sample (dc)
- Cool to LN temperature
- Sample every 2 seconds as sample warms
- $V_S = IR_S$
- $CV_{T,Measured} = V_{T@77\ K}$

Determining Temperature

- Used interpolation to "estimate" a functional relationship between measured voltage and what the corresponding temperature should be.

Interpolated T vs V

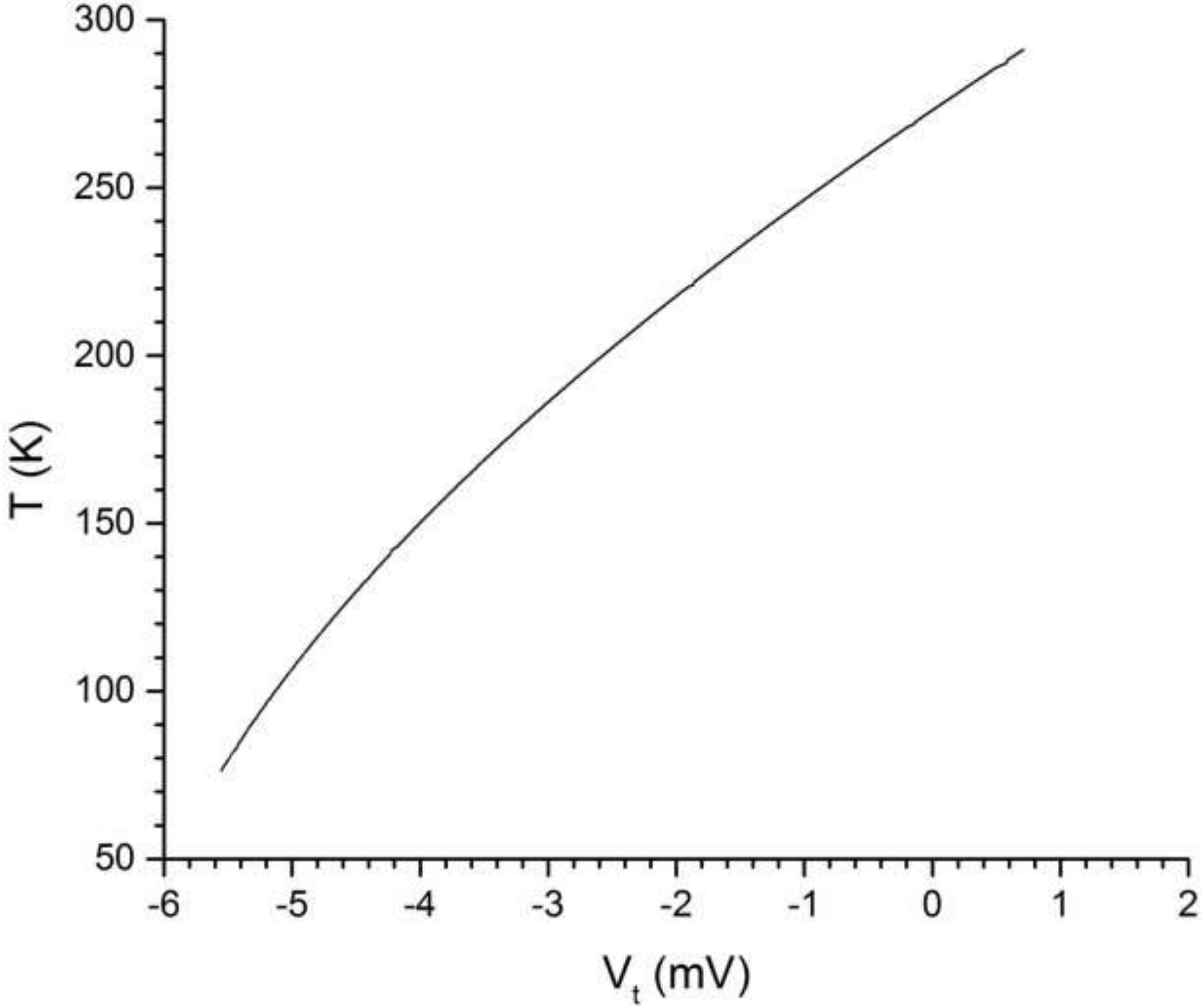


Figure 7. Plot of interpolated T vs measured V. Slight deviations from linearity can be observed.

R(T)

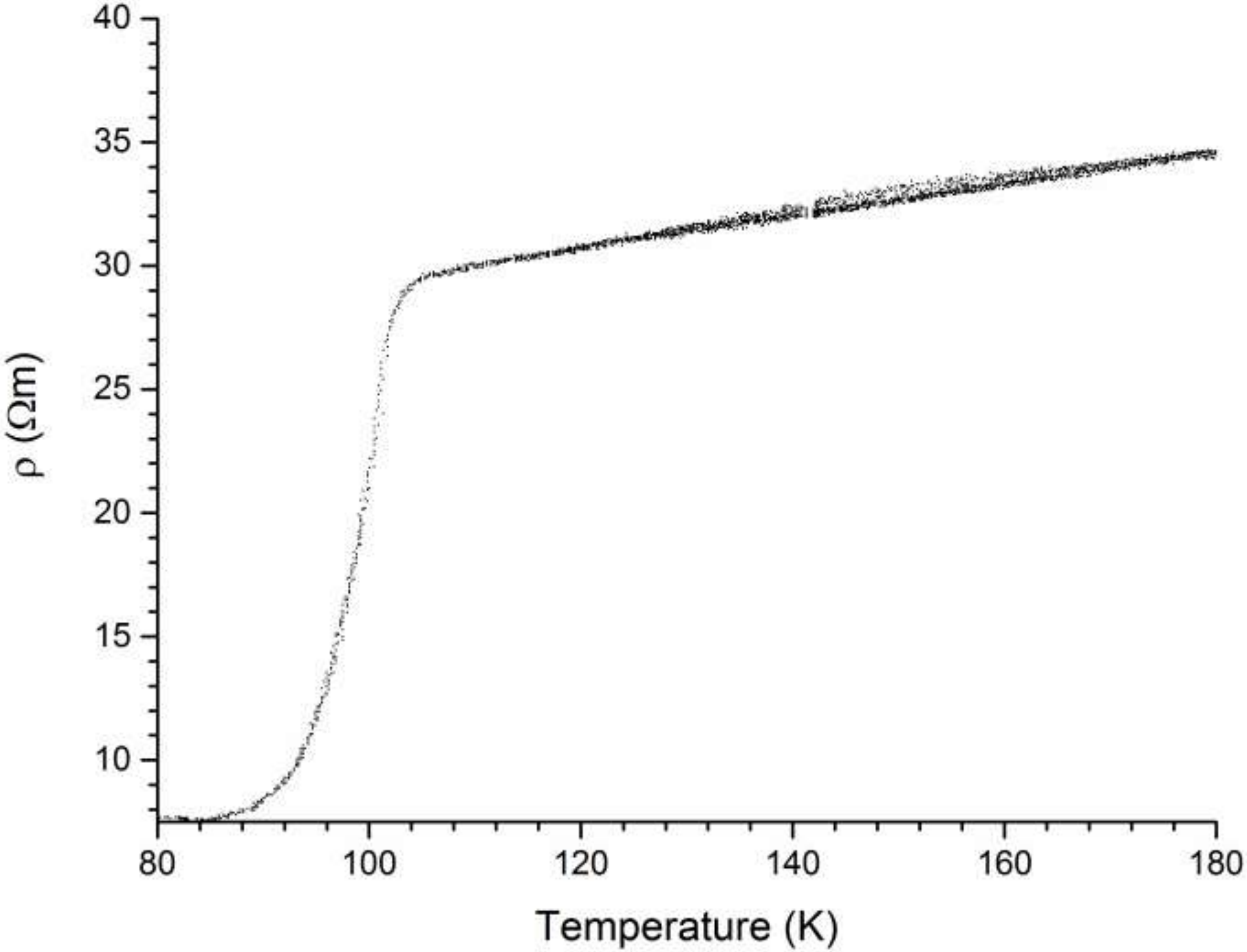


Figure 8. Plot of resistivity vs temperature.

Goal: Convert R into ρ_{ab}

- Want to extract ρ_{ab} from the bulk measurement

- $\rho(T) = \frac{1}{\alpha}(\rho_{ab}(T) + \rho_{wl})$

- α accounts for meandering current path and structural defects

$$\alpha = \frac{\rho'_{ab,B}}{\rho'_{B}} \qquad \rho_{wl} = \alpha\rho_{B}(0)$$

Polycrystalline Correction

- Fit background data of the form:

$$\rho(T) = \rho_B(0) + \rho'_B \mathrm{T}$$

$$\alpha = \frac{\rho'_{ab,B}}{\rho'_B}$$

$$\rho_{wl} = \alpha\rho_B(0)$$

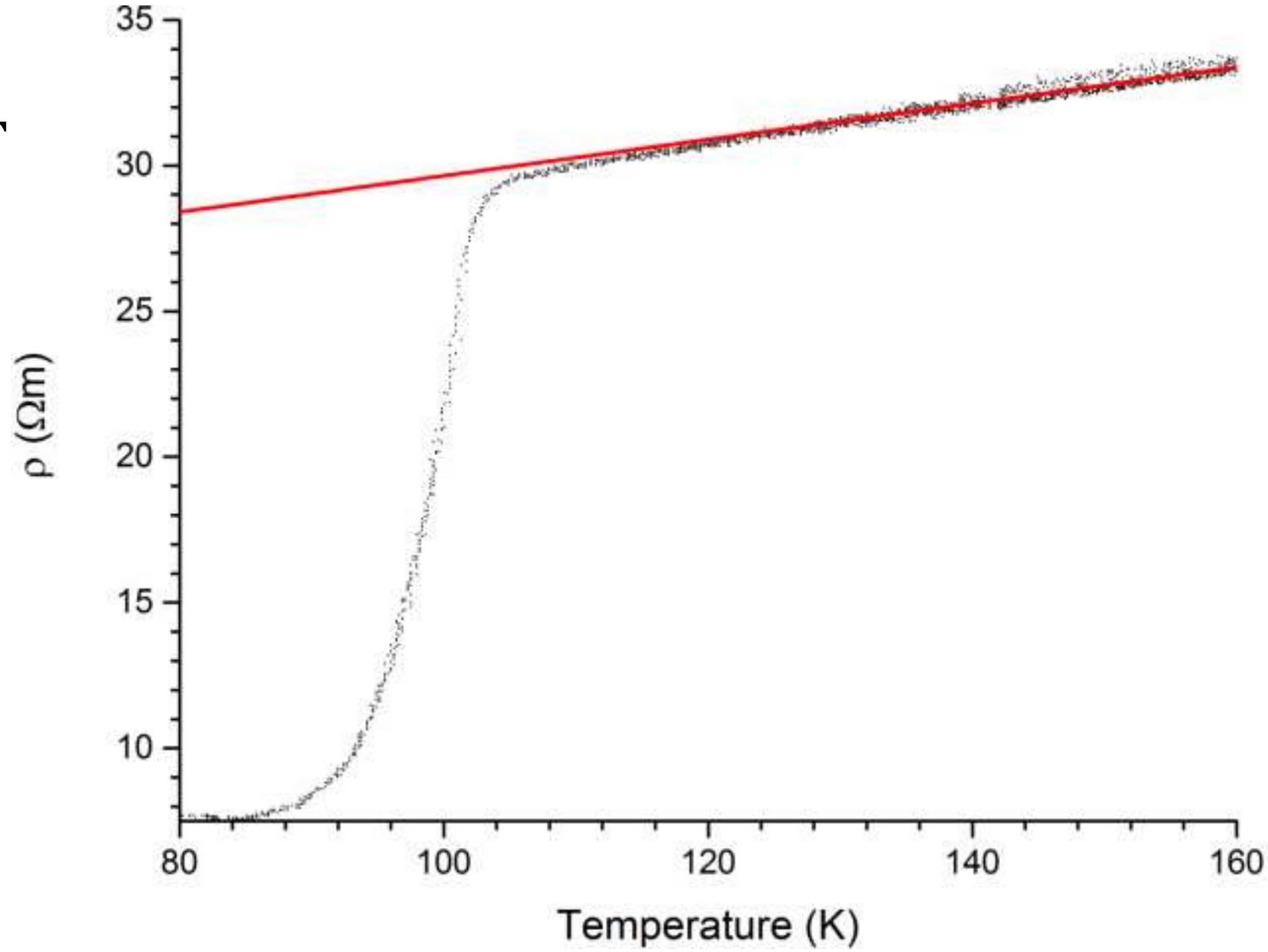


Figure 9. Background fit of the resistivity.

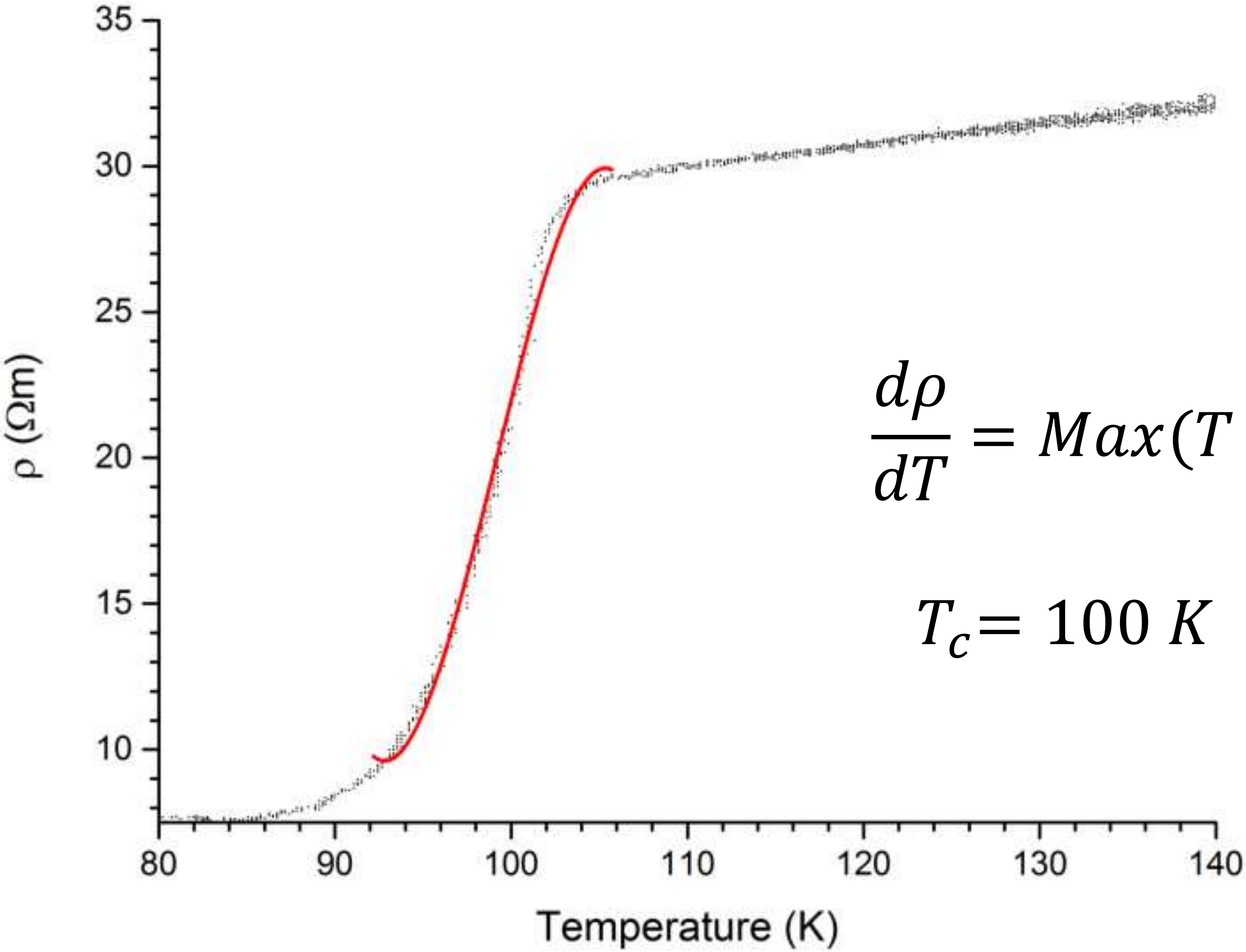
Theoretical Model

- Ginzburg-Landau Theory (GL) predicts how conductivity, $\sigma = \frac{1}{\rho}$, should fluctuate
- Characterized by $\Delta\sigma_{ab}$, difference between:
  - Polycrystallinity corrected resistivity
  - Expected high temperature (background) resistivity
- One parameter characterizes relationship:
  - $\xi(\varepsilon)$ – The Coherence Length
  - Look at $\varepsilon = 0$

Experimental Requirements

- Want to plot $\Delta\sigma_{ab}(\varepsilon)$ and fit for $0.02 \leq \varepsilon \leq 0.1$
- $\Delta\sigma_{ab} = \dfrac{1}{\rho_{ab}} - \dfrac{1}{\rho_{ab,B}}$
- $\varepsilon \equiv \dfrac{T - T_c}{T_c}$; gives a measure of proximity to the SC transition

Goal: Determine T_c of sample



$$\frac{d\rho}{dT} = Max(T = \ T_c)$$

$$T_c = 100\ K$$

Figure 10. Fit of $\rho(T)$ data to determine the critical temperature.

Theoretical Model

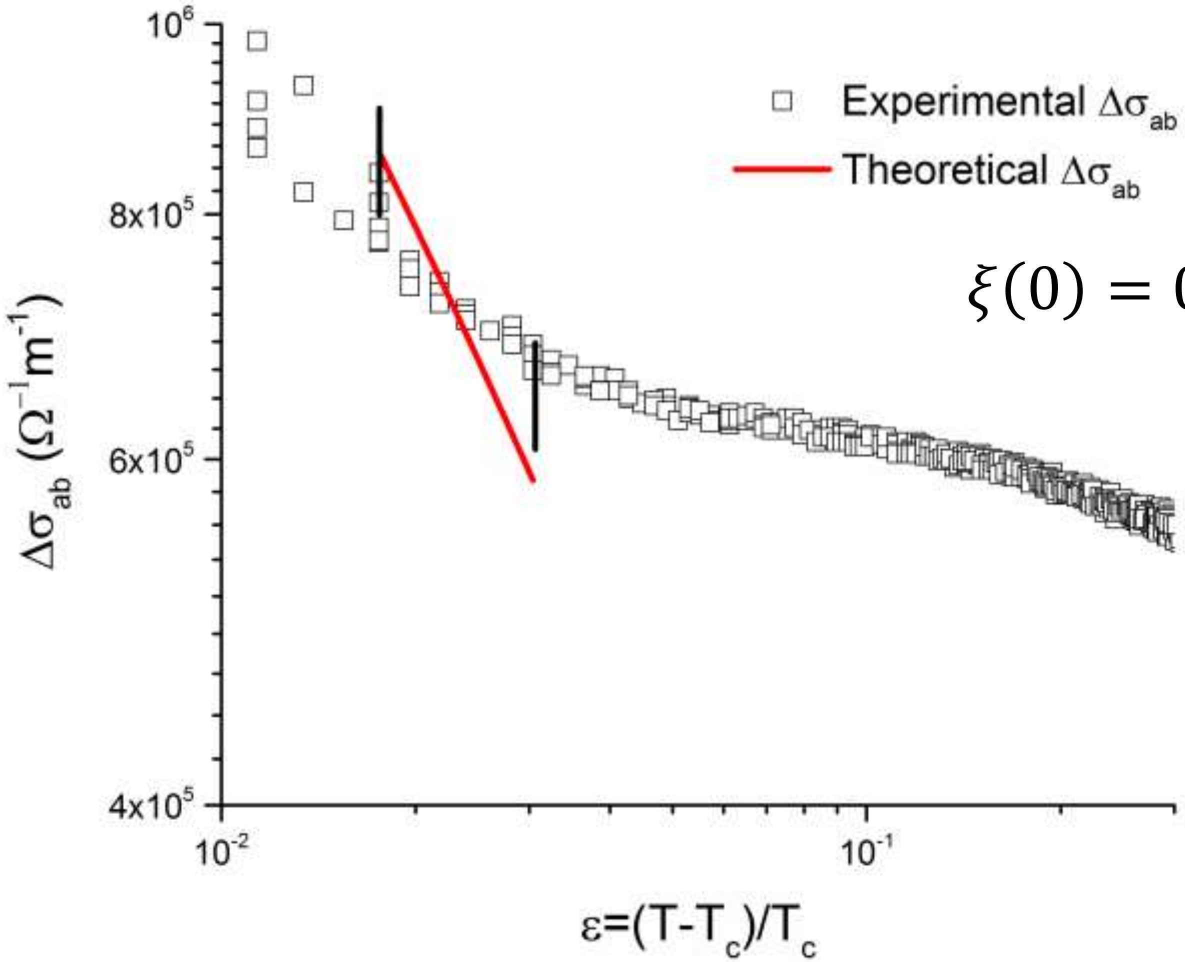
- $\Delta\sigma_{ab}(\varepsilon) = \frac{A_{AL}}{\varepsilon}(1 + \frac{B_{LD}}{\varepsilon})^{-\frac{1}{2}}$

- $A_{AL} = \frac{e^2}{16\hbar d}$ and $B_{LD} = (\frac{2\xi(0)}{d})^2$

Aslamazov-Larkin Constant

Lawrence-Doniach Constant

Goal: Experimental $\Delta\sigma_{ab}(\varepsilon)$ vs Theoretical Prediction



$\xi(0) = 0.54$ Å

Figure 11. Comparison of our experimental data (squares) with the theoretical fit (red).

Results

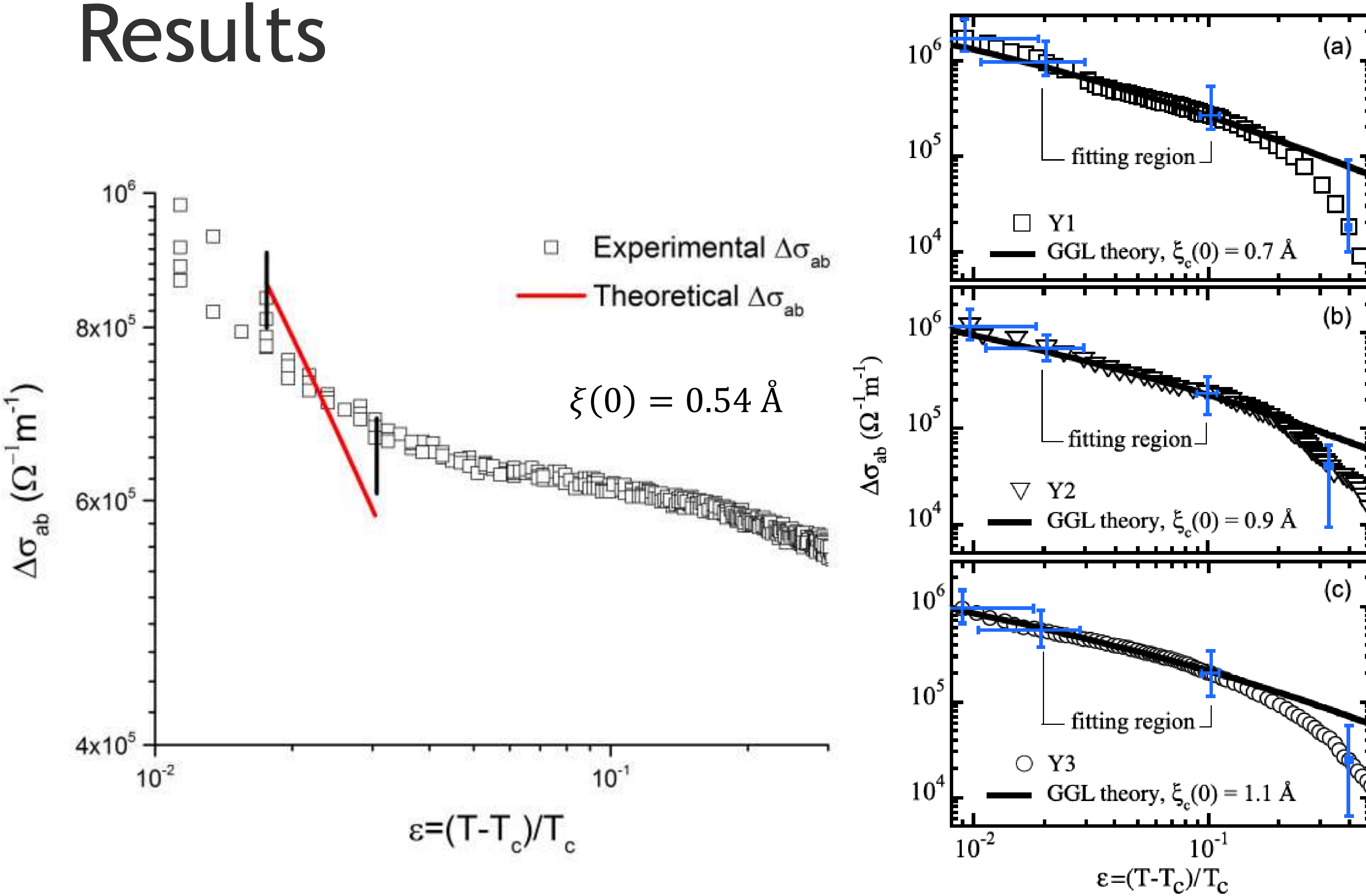


Figure 12. Comparison of our results (left) with Coton et al (right).

Conclusions

- Built a setup capable of measuring R and T of a YBCO sample.
- Able to observe thermal fluctuations via $\rho(T)$ deviating from linear background/rounded transition.
- Able to determine T_c of the sample.
- Able to compare experimental results with theoretical predictions, though results suggest much improvement is needed.

Future Work

- Revisit experiment, working out systematic errors, comparing with theory again.
- Compare bulk YBCO from several commercial sources to compare quality.
- Examination of YBCO thin films and comparison with bulk.
- Development of fabrication of YBCO at Wittenberg.

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Ginzburg-Landau Theory

- Characterizes SC transition based on macroscopic properties
- Introduces ψ
- Developed a spatially varying ψ
  - Phenomenological parameters (function of T)
  - Density of Cooper-Pairs
- Results in dissipation less current flow
- Concept of a coherence length

YBCO Structure

- The crystal structure is “Orthorhombic”

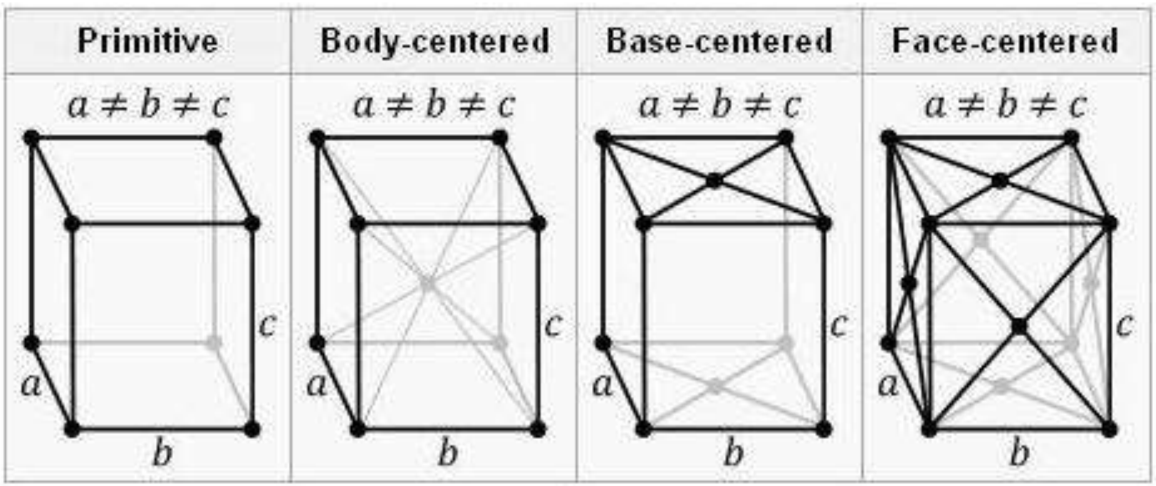

Figure 1. Examples of a few simple types of Orthorhombic crystal structures.

Amplifier for the Superconductor

- Non-inverting amplifier to measure V_S
- Opted for a G = 1000
- 3dB = 10 Hz

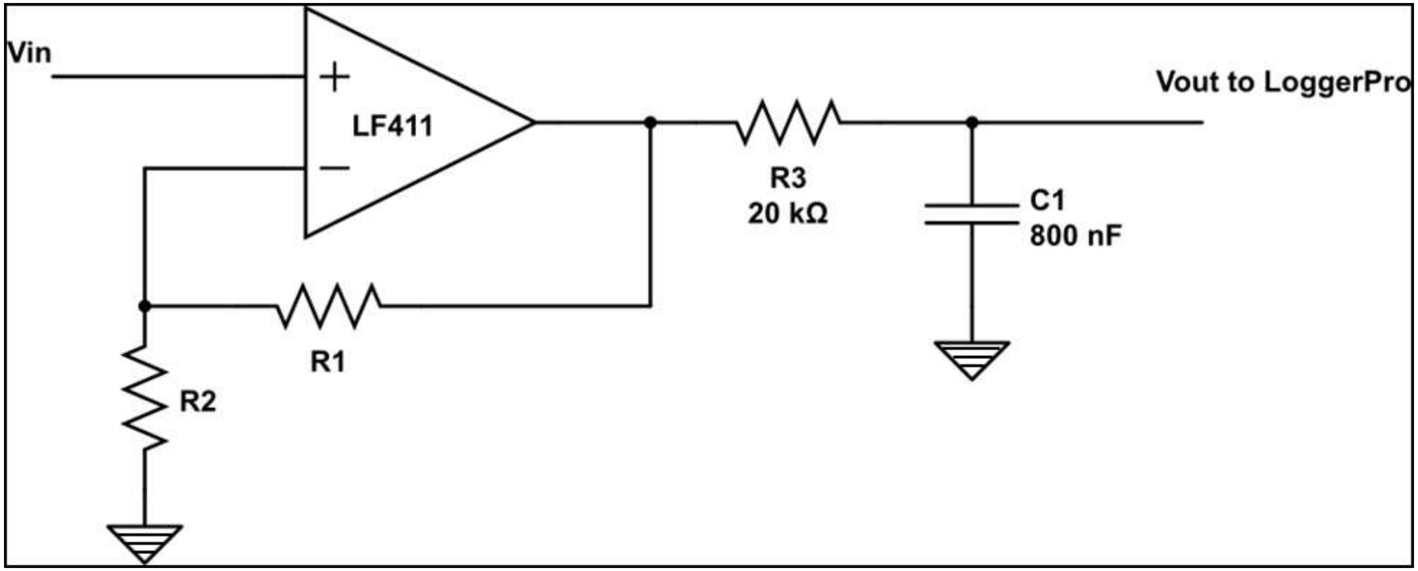

Figure 9. Schematic of the non-inverting amplifier used to measure sample resistance.

Why G = 1000?

- Want to avoid heating the sample, so we fix current
- I fixed, sample resistance fixes V_S
- An appropriate voltage gain chosen to yield full range of Logger Pro's ADC
  - Voltages represented as a 12 bit binary number (0-4096)
  - Want variations in signal to cover this full range

Thermocouple Amplifier

- Difference amplifier to measure V_T
- No electrical isolation of components required
- Opted for a G = 750
- 3dB = 10 Hz

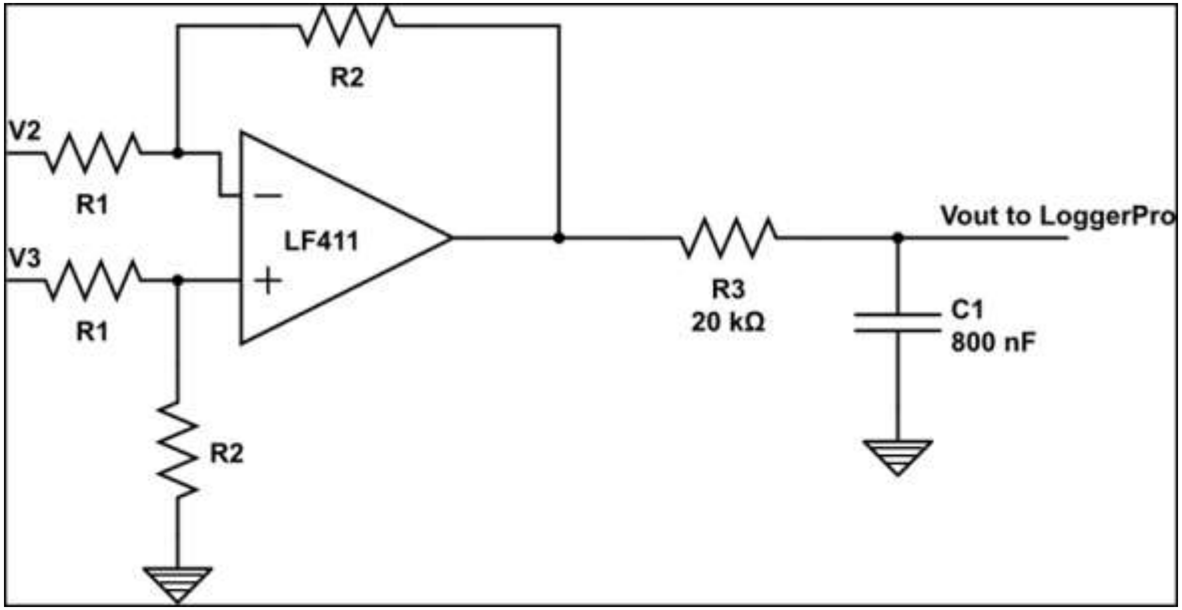

Figure 10. Schematic of the difference amplifier used to measure sample temperature.

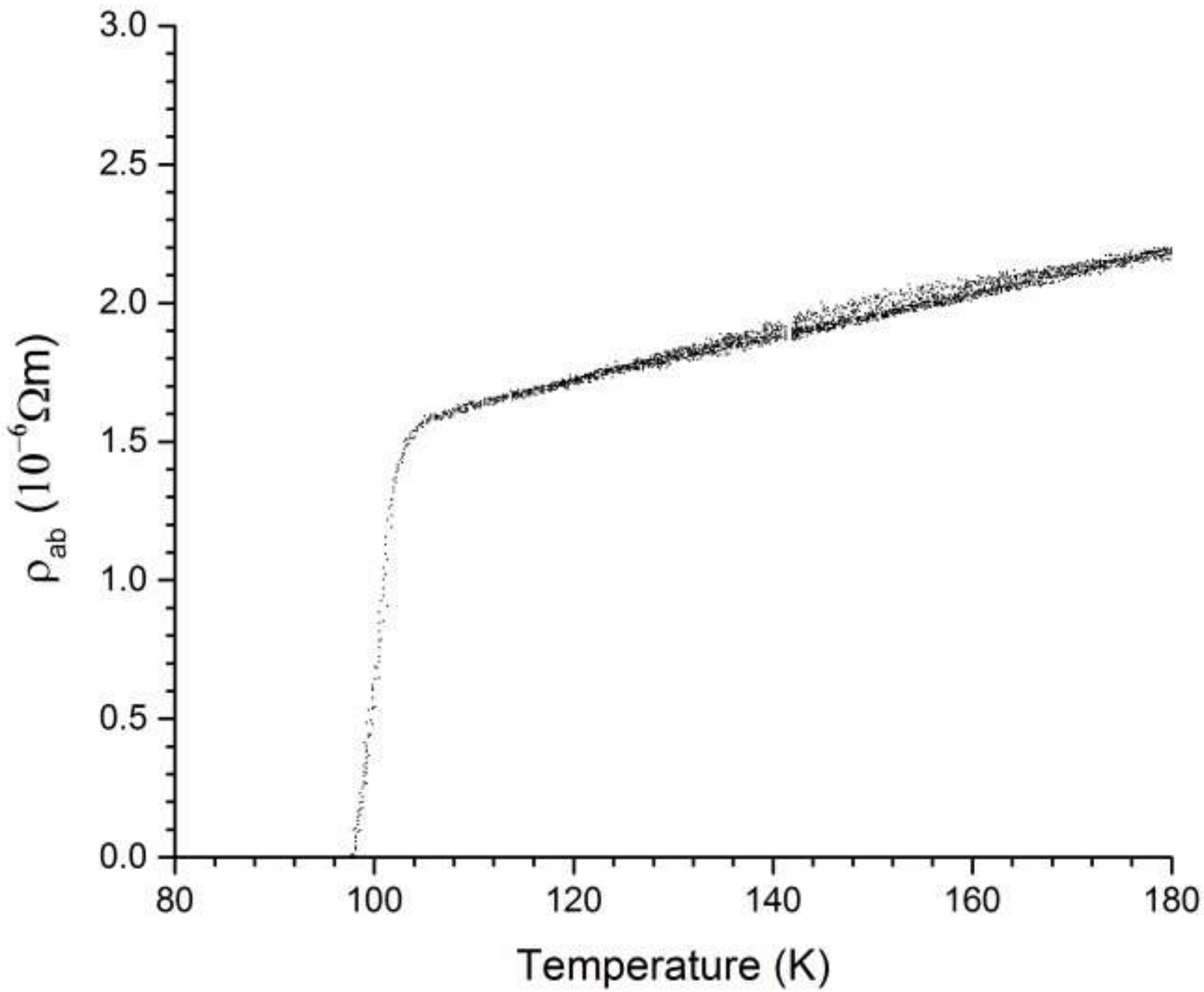

Figure 10. Plot of the in-plane resistivity vs Temperature.